Review Article

Investigation & Development of Micro Electrochemical Machining for Metal Removal with Micron Tolerances

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Abstract

The machining of materials on micrometer and sub-micrometer scale is viewed as the innovation without bounds. The present strategies for small scale producing generally are silicon based. These assembling strategies are not appropriate for use in requesting applications like aviation and bio-medical businesses. Miniaturized scale electrochemical machining (μECM) evacuates or removal material while holding micron tolerances and μECM can machine hard metals and alloy.

This review goes for building up a novel μECM using high frequency voltage pulses and close loop control. Stainless steel SS-316L and copper compound CA-173 were picked as the workpiece materials. A model was created for material removal rate (MRR).

The exploration concentrated the impact of different parameters, for example, voltage, frequency, pulse ON/OFF time, and postponement between pulse of the stepper motor on the machined profiles. Attempt information on little bored openings concurred with theoretical models inside 10%. Small scale burrs can be successfully evacuated by ideal μECM. A conciliatory layer enhanced the opening profile since it lessened 43% of corner adjusting.

Keyword: μECM, SS-316L, CA-173, MRR etc

Introduction of Ecm

Literature Review

Electrochemical machining expels material from an electrically conductive workpiece. The premise of this procedure is electrolysis, which is represented by the laws set up by Faraday.

Electrolysis

Electrolysis is the chemical reaction that happens when an electric current is passed between two conveyors plunged in a fluid arrangement solution. The fulfillment of this electric circuit is found by joining an ammeter to the framework and ammeter shows a perusing reading. A schematic plan of an electrolytic cell using copper sulphate as an electrolyte and copper wire as cathodes shows up in Fig 1.

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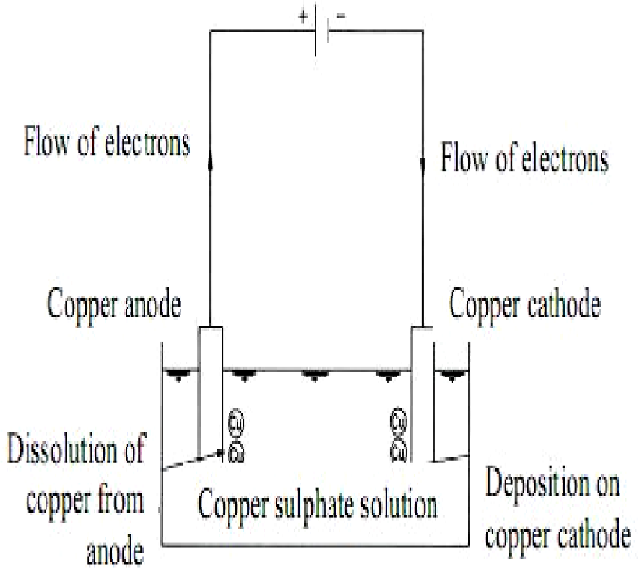


Figure 1

The chemical reaction is named cathodic reaction relying upon where they happened at the cathode, respectively. The essential distinction amongst electrolytes and metallic conveyors of power are current is conveyed by electrons in metals, current is conveyed by particles in electrolytes. ions are molecules that have lost or picked up electrons and they obtained a positive or negative charge. The decidedly charged particles go towards the cathode and the adversely charged particles go towards the anode. Hence, the electrolyte must be nonpartisan, there must be a harmony between the aggregate positive charge and the negative charge. At the completion of the response, the measure of material lost by one of the anodes is equal to the measure of material picked up by the other. Subsequently, this procedure can be utilized for both material expulsion and expansion. The utilization of electrochemical response are electrolysis are electroplating and electro-cleaning.

Electrochemical Machining

Micro scale Electrochemical machining is a material evacuation prepare equivalent to electro- cleaning. In this procedure, the work piece to be machined is made the cathode and the apparatus is made the anode of an electrolytic cell with a Na-cl arrangement is utilized as an electrolyte. The apparatus is regularly made of copper, metal, or stainless steel. The apparatus and the machined piece are set so there is a hole between 0.1mm to 0.6mm between them (Rajurkar et al. 1999). The apparatus is outlined with the goal that it is the correct opposite of the component to be machined. On association, a potential contrast between the anodes and in this way when sufficient potential distinction vitality is accessible between the device and the machined piece, positive metal particles leave the machined piece. Since electrons are expelled from the machined piece, oxidation response happens at the anode which can be spoken to as,

$$M \rightarrow Mn^{+} + ne^{-}$$

where n is the valence of the workpiece metal. The electrolyte accepts these electrons resulting in a reduction reaction which can be represented as,

$$nH_2\,O + ne^{-} \rightarrow n/2H_2 + n\,OH^{-}$$

Hence the positive ions from the metal react with the negative ions in the electrolyte forming hydroxides and thus the metal is dissoluted forming a precipitate. The electrolyte is constantly flushed in the gap between the tool and the workpiece to remove the unwanted machining products which otherwise would grow to create a short circuit between the electrodes. The electrolyte also carries away heat and hydrogen bubbles. The tool is advanced into the workpiece to aid in material removal (McGeough 2005). A schematic of a cell used for electrochemical machining is shown in Figure 2.

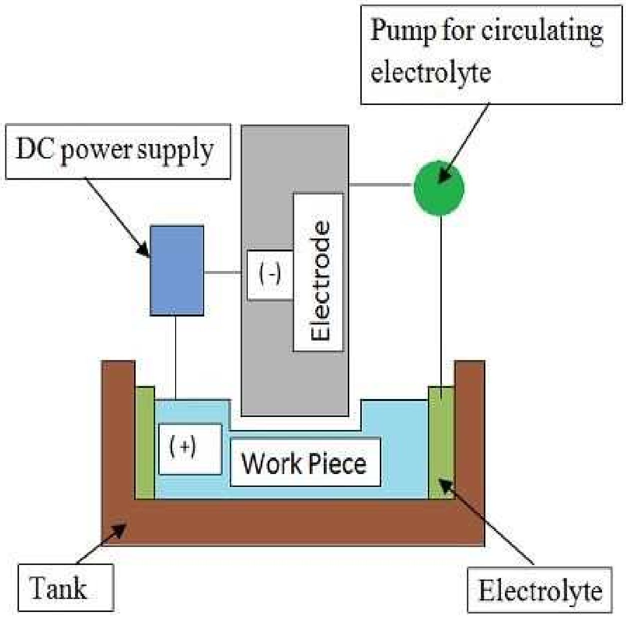


Figure 2

Schematic of ECM

Modeling

The formula for material removal rate (MRR) are for electrochemical machining using direct current. A model was developed for the calculation of MRR while using pulsed current.

Model for Material Removal Rate

The created display gives the volume of material expelled for each pulse of current. The model was determined under the suspicion that material is expelled just amid the pulse ON term and stream rate is sufficient to flush away the reaction items. Equation gives the volume of material expelled V*u* for each pulse.

$MRR = V_u / \tau$

Where,

V_u is the volume of material removed for one pulse

τ is the pulse duration.

Calculation of Electrochemical Constant

The formula for calculating electrochemical constant for single material elements was given in Equation.

C = *Aw/ZF*ρ

$$C = \frac{100}{\sum_i \left(\frac{x_i z_i}{A_i}\right) \rho F}$$

$$\rho = \frac{100}{\sum_i \left(\frac{x_i}{\rho_i}\right)}$$

where ρ is the thickness of the alloy, F is the Faraday's constant, x_i is the rate of i^{th}element in the alloy, Z_i is the valence of i^{th}element in the alloy, A_i is the nuclear weight of i^{th} component or element in the alloy, and ρ_i is the thickness of the i^{th} component in the compound or alloy.

Calculation of Electrochemical Constant for CA-173

The composition of CA-173 alloybelow in table (ASTM B196).

Element	Percentage (%)	Valency	Atomic mass (g/mole)	Density (g/cm^3)
Copper (Cu)	97.7	2	63.57	8.96
Beryllium (Be)	1.9	2	9.012	1.848
Lead (Pb)	0.4	2	207.2	11.34

Composition of CA-173 alloy (ASTM B196)

From above equation

$$\rho_{CA-173} = \frac{100}{\frac{97.7}{8.96} + \frac{1.9}{1.848} + \frac{0.4}{11.34}} = \frac{100}{10.9 + 1.028 + 0.035}$$

$$= \frac{100}{11.963} = 8.36 \frac{g}{cm^3}$$

$$C_{CA-173} = \frac{100}{\left(\frac{97.7*2}{63.57} + \frac{1.9*2}{9.012} + \frac{0.4*2}{207.2}\right)*8.36*96500}$$

$$= 3.54*10^{-2} \frac{mm^3}{A.s}$$

Calculation of Electrolyte Resistivity

The electrolyte resistivity was measured in a roundabout way. The conductance of the electrolyte was discovered utilizing Thermos Orion micro electrodes conductivity test. The conductance measured was 29.9 millisiemens. The conductivity was figured utilizing Equation below.

Cell Conductance * Cell Constant = Conductivity

The cell constant value was obtained from equipment manual to be 1 cm^{-1}The conductivity obtained using Equation (19) is 0.0299/Ω-cm. The resistivity was measured as,

$$Resistivity = \frac{1}{Conductivity} = 33.44\ \Omega cm$$

Model for Deburring

A model was developed which enabled to calculate the time and speed of electrode necessary to deburr a flat component.

The burrs on the surface after micro electro-chemical machining (μECM) were in the form of small hemispheres as shown in Figure .

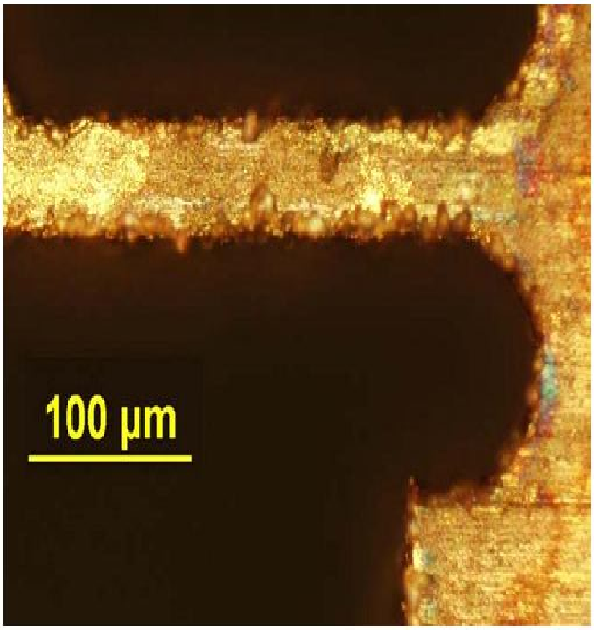


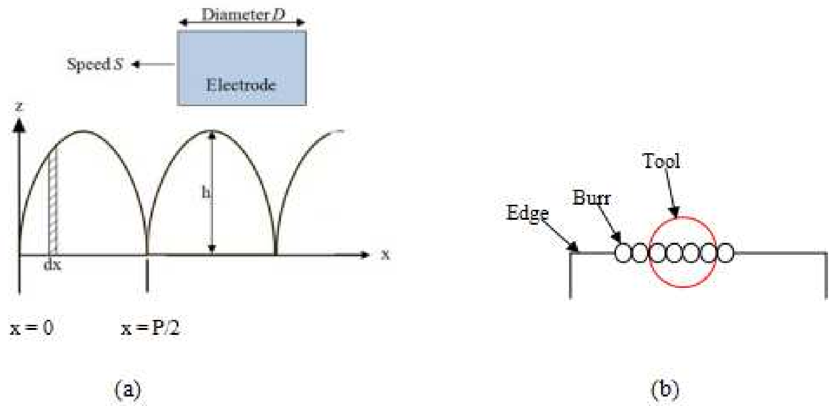
Figure 3

Distorted Burr along edges of a machined piece after µECM

Assumptions:

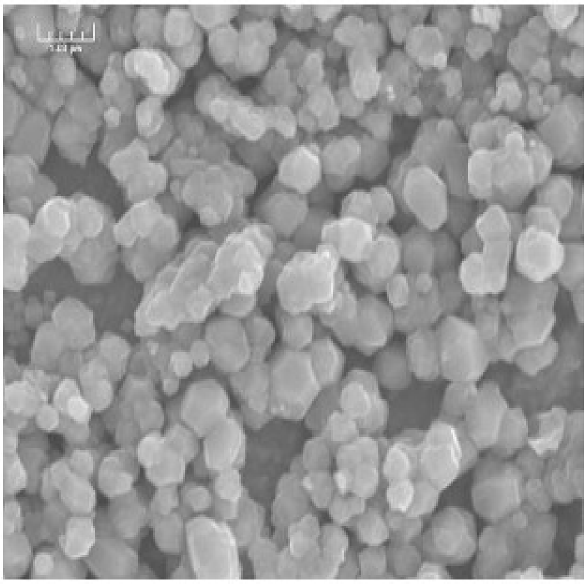
1. Workpiece continuous distorted burrs as half of sine wave.
2. Smoothing burr in work mode that is removing burrs just under the electrode.
3. Smoothing the burr one edge at a time.

Consider the case as shown in Figure (a) where burrs are modeled as an absolute sine wave of magnitude h and period P. A top view of the burrs along the edge of the workpiece and position of the tool is shown in Figure (b).



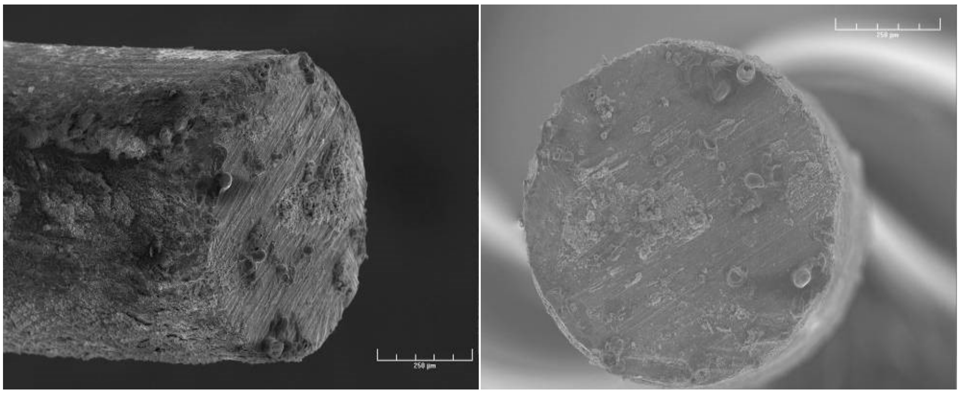
Results and Discussion Analysis of Holes Drilled in Copper

Figure shows some kind of layer formed on the surface of CA-173 after machining. It was doubted that this layer impeded machining and more tests were performed to taken out the composition of the layer.



Surface of CA-173 workpiece after µECM at 0.5 KHz and 16 VPP

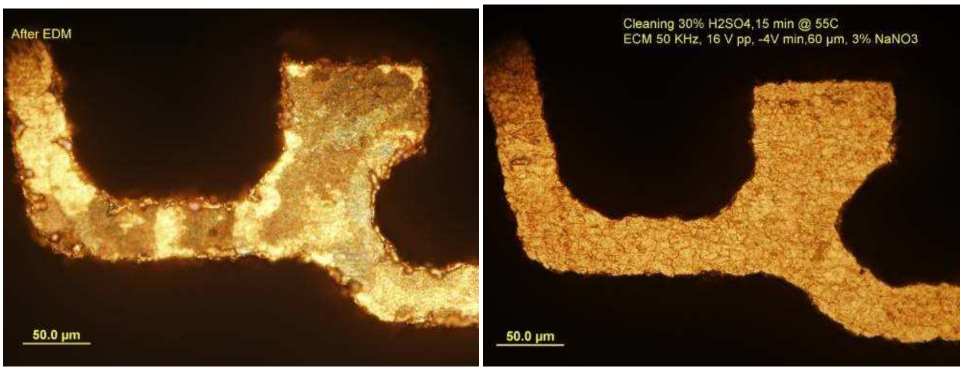
Figure shows images of stainless steel electrode that was used to machine hole in CA-173.There was a clear sign of deposition to the electrode. (a) shows the bottom of the electrode whereas (b) shows a side view of the electrode.



(a) (b)

Stainless steel electrode after machining CA-173 workpiece at 0.5 KHz and 16 Vpp

As thr result of µECM was successfully applied to deburr micro components. Figure shows (a) and (b)the component with burrs along the edges.



(a) (b)

Micro electronic component with burrs Component deburred with µECM at along edges.50 KHz ,16 Vpp and ø500 µm tool

Table 1.Parameters for deburring calculated by model

Number of pulses	684000
Speed (µm/s)	137
Time (s)	14.62

The observational values which provide the best quality of deburred surface are tabulated in Table.

Table 2.Experimental parameters for deburring

Speed (µm/s)	125
Time (s)	16

The plot obtained from EDS on a stainless steel electrode that was used to drill 8 holes in CA-173 is shown in Figure. The composition of each element and their source are tabulate din Table

Results of quantitative analysis on stainless steel electrode.

Element	Composition (%)	Source
Nickel (Ni)	41.04	Coating on electrode
Iron (Fe)	19.07	Tool material
Copper (Cu)	18.79	Workpiece material
Oxygen (O)	9.42	Oxidation
Sodium (Na)	6.9	Electrolyte

Conclusions and Recommendations

Conclusions

A novel µECM with vibration polishing system was developed:

- Using high frequency pulses.
- A model was developed for material removal rate using pulsed current.
- The system was used to successfully form micro holes and for profile refinement.
- Experimental data on small drilled holes agreed with theoretical data within 10%.
- Micro burrs can be effectively removed by optimal µECM setup.

Recommendations

- Future work includes using pulsed laser to enhance the process. It is assumed that the pulsed laser would enhance the rate at which the reaction products are flushed out of the machining zone resulting in a higher material removal rate. The pulsed laser heat up the machining zone locally increasing the rate of anodic dissolution.
- The model for material removal rate can include the effect of pulse OFF duration and flow rate to accurately predict the material removal rate.

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